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1 Executive Summary

Background

AirCell Inc. is currently fielding a nationwide airborne cellular network, reusing terrestrial cellular frequencies to provide airborne services. This system utilizes AMPS technology, with few but significant modifications; AirCell utilizes horizontal polarization for transmission, which naturally provides cross-polarization rejection at non-participating, vertically polarized terrestrial cellular sites. AirCell also benefits from essentially line of sight transmission characteristics, which allows its airborne transmitters to communicate with ground sites using extremely low reverse channel power, which further mitigates the possibility of observable interference.

AirCell has previously demonstrated that despite concerns voiced by non-participating cellular carriers fearing harmful interference to their systems, they do not in fact cause harmful interference. Several tests were performed, including a formal flight test performed in 1997 by an impartial third party, TEC Cellular. This test was witnessed by the Federal Communications Commission. Opposing parties also participated in and witnessed the test. The test and the results therefrom are described in detail in "Final Report, AirCell Flight Test, July 10-11, 1977" by C. J. Hall, P.E. and Ivica Kostanic, then of TEC Cellular, Inc.

Further tests have been conducted, including some exclusively by opposing parties. In June 2000, the FCC renewed AirCell's waiver, essentially ruling that no credible evidence existed to substantiate claims of harmful interference to AMPS operations on the ground.

Current Issues

Technology does not stand still. More and more terrestrial cellular operators are deploying advanced cellular protocols in the search for more capacity and enhanced feature sets. IS-136 Time Division Multiple Access (TDMA) is now quite popular and widely fielded. As use of this technology grows, it is prudent for AirCell to conduct a test to determine whether AirCell AMPS frequency reuse is compatible with terrestrial TDMA operations, which are phase modulated - QPSK - rather than linear FM as utilized by AMPS. The potential for cross technology interference - that of AirCell AMPS impacting on terrestrial TDMA operations, is the subject of the test described herein.

IS-136 TDMA Testing

TDMA testing was carried out at an operating US Cellular site in Northwest Illinois. The Lena site is rural, and is equipped with Nortel dual mode AMPS/TDMA equipment. This equipment is widely used throughout the US, thus it is representative of 'typical' hardware found in the US.

To conduct this test, AirCell again drew on impartial outside parties, including WSE, SAFCO Technologies, and others. These parties were tasked to design an accurate, conclusive test plan, collect and protect the data, postprocess it to extract information, document the results, and finally draw conclusions regarding the potential impact AirCell operations would have on terrestrial TDMA operations.

The intent of the digital compatibility test was to objectively measure the effects of AMPS reverse channel signals (as from AirCell equipped aircraft) and noise (the background conditions found in areas having various population densities) on the reverse link performance of an 800 MHz cellular TDMA base station. The chosen digital call quality metric is Bit Error Rate (BER) on the reverse channel. Bit Error Rate is a parameter commonly used for system optimization and quality assessment by cellular carriers operating TDMA systems. The following data was obtained/measured to create a comprehensive data set for analysis:

- Background composite noise and interference signal levels.
- Received signal level of TDMA reverse channel signals for typical subscriber calls.
- Received signal level of TDMA reverse channel signals during a drive test of the cell coverage area.
- AMPS (AirCell) airborne mobile reverse channel signal levels collected at a non-AirCell equipped observer site. (Data from previous flight testing.)
- IS-136 cellular base station receiver BER performance in the presence of 'white' noise and AMPS interference.

This comprehensive data set was used to construct a model of the interference effect caused by AMPS carriers on reverse channel BER performance at a terrestrial TDMA site. Previously obtained AirCell flight test data showing actual observed levels of AirCell AMPS reverse channel signal at non-AirCell observer sites were then used to predict the impact AirCell operations will have on terrestrial TDMA cellular sites in general. From this analysis, a determination was made whether the systems can coexist without harmful interference to terrestrial IS-136 operations.

Bit Error Rate (BER) is typically utilized as a primary *quality* metric in optimizing TDMA systems. The IS-641 Algebraic Code Excited Linear Predictive (ACELP) vocoder used in today's IS-136 TDMA phones provides good speech quality in systems using a 2-3% BER design goal.

Other metrics are of course used in cellular optimization, including signal strength, evaluations of adjacent channel signal strength, and signal to interference ratios relative to cochannel terrestrial reuse, but the quality of the speech heard by the user is ultimately a function of BER. If the BER is low, speech will be accurately reproduced (to the fidelity limits of the vocoder). If the BER is high, the vocoder does not have all the information needed to reproduce the speech and the quality degrades. The subscriber typically neither knows nor cares *what specific mechanism (noise, fading, or interference)* causes the bit errors – the subscriber wants speech reproduced cleanly.

TDMA cellular carriers have, both in published papers and in the direct experience of the authors, consistently adopted a 2% BER as their system performance target. This is a bit more stringent than the 3% BER that EIA standards imply to be adequate. (See TIA/EIA-136-280, paragraph 2.3.2.5.3, Table 5 for example.) Therefore, for the purposes of this test, we considered 0-2% BER as the target for 'good' voice quality during calls. Other values of BER were bracketed in ranges of 2-5%, 5-10% and greater than 10%. These are not considered good quality calls, and although carriers are free to set BER thresholds higher than 2% to trade quality and capacity, the authors have seen no evidence that networks are set to higher BER thresholds in practice. The test setup allowed accurate measurement of BER with respect to the reverse channel operating point. The shape of the BER curve was relatively linear below 2% and above 10%. Evaluation in the bracketed ranges allowed characterization of the more nonlinear portions of the curve. Analysis of the BER impact focused on values around the 2% threshold.

Experimental Approach

To test the performance of a typical site transceiver in the presence of noise and interference, an HP 8921 cell site test set with the TDMA appliqué was utilized. The test set RF output was routed through a directional coupler, and then into the site receive multicoupler. The site transceiver then sent its RF output back to the HP 8921 so 'calls' could be established in a closed, cabled measurement system with known losses. Cable and coupler losses were measured and normalized out of the measurements, so the BER performance of the site radio could be determined with respect to its receive multicoupler port. This port is common to all vendor equipment, so it provides a reference point representative of all site equipment implementations. *This is the same reference point used in the 1997 flight test and report, so signal levels from the tests may be directly compared.*

The directional coupler provided an injection point which allowed 'white' noise and narrowband interference to be injected simultaneously. The 'white' noise was used to represent the multiple cellular frequency reuses typical in a terrestrial system and other manmade noise at levels typical of rural, suburban, urban, and dense urban environments. The levels injected were previously established, as discussed in the 1997 test report, and based on industry-accepted data.

The AMPS interference source was an HP signal generator modulated with a SAT tone only. This modulation was chosen for a combination of theoretical and empirical reasons. Qualitatively, it can be shown that per unit transmitted power, the *most* disruptive interference to a QPSK signal is a *coherent* CW signal. The vector sum of such a signal with the signal of interest places a constant offset on the s-plane bit decision regions, causing the decision regions to be non-optimal, producing a relatively high number of bit errors. The *least* disruptive interference is wideband (gaussian) noise across the entire bandwidth of the QPSK signal, for which the demodulator is optimized. Of the possible AMPS waveforms, the closest the signal can come to CW is a voice channel transmitting SAT only. With voice modulation, spectral occupancy is wider, and the widest spectral occupancy is achieved by signaling tone or digital messaging. The wider the occupancy of the FM signal, the more it looks like incoherent noise to a QPSK demodulator.

An experiment was conducted at Lena to confirm this reasoning, and SAT-only AMPS modulation was chosen as the most disruptive of AMPS signals with respect to TDMA. Thus, it was chosen for the BER impact characterization.

For each wideband noise level (rural, suburban, urban, dense urban), the BER performance vs. received TDMA signal level was characterized. Then, an AMPS signal was injected, and the test repeated. The test was again repeated, each time increasing the AMPS signal level, producing a two dimensional matrix of BER values for a given environment (i.e. rural) in which TDMA signal level and AMPS interference level defined the rows and columns, respectively.

With these matrices in hand, it became possible to run computer simulations in which 1997 AirCell flight test data provided the AMPS signal level values/distributions, and actual Lena subscriber call signal strengths provided the TDMA signal levels. – The impact of AirCell operations on BER could be directly computed.

To record actual subscriber reverse channel signal levels at Lena, the chosen method was to directly poll the TDMA site transceivers for activity and RSSI information on each timeslot once a second. This allowed normal site operation, and obtained data for all TDMA calls placed at the site. Unlike the Madill site transceivers in the 1997 test, the more modern Nortel radios at Lena were found to report RSSI information with good linearity and accuracy. They were carefully characterized and used as the primary source of terrestrial call data.

A drive test of the Lena area was also conducted to further assure that the site was behaving as a 'typical' rural TDMA site should, and to provide correlated (time aligned) forward/reverse channel data for analysis.

The most important analysis step calculated the bit error rate for the subscriber call data, with and without AirCell operations overlaid. The difference in BER provided the direct impact that can be expected from AirCell operations.

Experimental Conditions and Assumptions

To conduct the experiment and interpret the results, a series of engineering assumptions and choices were made, some of which are mentioned above. (These are discussed in detail as they arise in context of later sections.) Overall, experimental conditions were chosen to control as many variables as possible, to remove uncontrolled influences which could affect experimental outcome. Likewise, due to the complexity of the situation, it was necessary to make simplifying assumptions during analysis. In both cases, a deliberate effort was made *not* to choose conditions or assumptions that unduly favored the AirCell case. Rather, conditions and assumptions were chosen to be either neutral or *unfavorable* to AirCell. As a result, the experimental results and their interpretation herein overpredict the interference potential of AirCell operations.

The conditions and assumptions unfavorable (or at best neutral) to AirCell, along with an estimate of the impact of each assumption (in isolation) are as follows:

Table 1.1 Test and analysis conditions/assumptions affecting observed interference impact

Condition/Assumption	Difference relative to 'typical' or 'real world' situation	Estimated impact for factor in isolation relative to AirCell case
2% BER operating point for 'Good' call quality	Most carriers set BER at 2%, but EIA/TIA specifications imply 3% BER as the call quality goal	BER target used is probably too low by 0-1%
Non-fading, hard-cabled RF signal path	Terrestrial fading includes Rayleigh and Log-Normal fade components. (IS-136 forward error correcting coding is designed to absorb some bursty errors due to fading.)	Target BER in non-fading test environment should be reached at lower received reverse link power level than in 'real world' (with fading). AirCell (AMPS) signal (at a constant level) is <i>relatively stronger</i> compared to this weaker TDMA signal level, so evaluation should show higher than 'real world' BER impact.
Fixed interference threshold levels used in comparisons to 1997 flight test data	Interference threshold is dynamic, depending upon local conditions	Proximity to noise sources can raise local noise floors at specific cell sites - which raises AMPS interference threshold.
1997 flight paths radial to site	Aircraft paths are random, often grazing only edge of observer site interference susceptibility region	Interference calculations effectively based on assumption that AirCell subscribers fly point-to-point directly over cochannel terrestrial sites.
Terrestrial sector antennas assumed susceptible to interference over 180° azimuth.	Typical sector antennas have 105° to 120° 3dB azimuth beamwidth	Up to 1.7x overestimate of interference impact to sectorized sites.
AMPS interferers utilized SAT-only modulation	Least modulation possible for AMPS signal, thus highest impact to QPSK demodulator	Apparent interference level during test increased by 0-2dB depending upon instantaneous AirCell subscriber modulation.
AirCell traffic assumed to be 2000 Erlangs nationwide	AirCell predicts 200 Erlangs at peak hours for mature system.	10X overestimate of traffic to simulate high-traffic corridor. Overestimate is greater at non-peak-traffic times
Airborne impact assumed to take place to 10 miles from terrestrial TDMA site	1997 flight test data indicated a 5 mile radius to be more realistic	Region of interference susceptibility roughly 4X overestimated. Thus: With 2000 Erlangs traffic, 5 mile susceptibility radius; probability that ≥1 AirCell subscriber(s) are present and transmitting (on <i>any</i> channel) is 0.041 probability, so:

Condition/Assumption	Difference relative to 'typical' or 'real world' situation	Estimated impact for factor in isolation relative to AirCell case
		Given 2000 Erlang traffic, probability of ≥ 1 interferer present is overestimated by factor of 3.7
Flight test data used AirCell serving cells >75 miles away	Flight paths generally random relative to AirCell locations	Operations at cell boundaries raise AirCell subscriber unit transmit power and interference potential.
Forward path was run 'hot' enough to preclude forward link bit errors	Forward link often responsible for TDMA perceived call degradation	Zero, or up to total masking of reverse interference impact, depending upon forward link conditions.
	Neglects subscriber unit desense when near non-TDMA participating sites	Desense can impact forward link by up to 6 dB, causing bit errors and call drops.
Dynamic power control not allowed to compensate for increases in BER	<p>This worst-case assumption places all subscribers effectively at cell edge where susceptibility to interference is greatest.</p> <p>All TDMA subscribers effectively assumed to be at maximum reverse channel transmit power.</p>	<p>TDMA system normally responds to high BER by simply increasing reverse power a step - <i>If a subscriber unit has <u>any</u> power steps left, AirCell impact will be <u>automatically canceled</u>.</i></p> <p>>2 dB for 81% subscribers (those at less than 90% of nominal cell radius).</p>

The above assumptions each have effects varying from essentially nil up to a complete masking of the AirCell interference potential. While these factors *do not* add directly (2 dB plus 2 dB *does not* necessarily equal 4 dB in considering multiple factors above) it is clear that, taken together, the potential for interference impact has been *significantly* overestimated.

The degree of overestimation due to synergy in combinations of these factors can naturally be debated, but the interference potential represented by the experimental data and calculations presented herein should, in the authors' best professional opinion, be regarded as significantly worse than any realistic 'real world' conditions. In the authors' opinion, the cumulative, average effect of these factors *combined* cause the interference estimates presented herein to overpredict, *by at least one, and possibly two orders of magnitude*, the potential for interference resulting from normal AirCell operations.

Experimental results and conclusions

Experimental results characterizing TDMA receiver performance in the presence of interference are presented in detail in Section 4. Later sections compare the receiver performance data to 1997 flight test measured interference signal levels to predict 'real world' BER impact expectations in various situations. The assessment then includes the probability that prerequisites for interference to manifest are met, including probabilities that TDMA subscribers and AirCell subscribers are cochannel and transmitting in sufficient proximity that an interference impact may manifest. When this data is weighted by the typical spatial distribution of terrestrial callers (using land use category), the impact is reduced to a national average expectation.

The BER analysis results are summarized in Table 1.2 below. This table has several columns:

- 1) The first indicates the case of interest; defined by combinations of land use category, AirCell subscriber altitude, AirCell serving cell antenna configuration (omni or 'smart'), and gives the signal strength at which 2% BER is exceeded.
- 2) The second column indicates the BER impact expected under the test conditions - in which an interference signal is deliberately being injected.
- 3) The third column estimates the increase in BER that a terrestrial caller might experience while placing a call in a given land use category, taking into account the probability that an AirCell caller may be cochannel, closer than 5 miles to the serving terrestrial cell, and typical channel counts/configurations for the terrestrial cell.
- 4) The fourth column indicates the percentage of the cellular calls placed in the US for the land use category indicated in Column 1 of that row.
- 5) The fifth column indicates subtotals derived by multiplying columns 3 and 4, which are then summed vertically to provide a *nationwide BER impact estimate for specific AirCell cell configurations and subscriber altitudes. (This summed row is presented in blue.)*

It's interesting to note that IS-136 systems control subscriber transmit power not only by observing Received Signal Strength (RSSI), but BER as well. *IF* a BER impact from any interference source pushes a call beyond the target BER (usually 2%) the system responds by asking for an increase in subscriber transmit power. Table 2.2 shows the incremental power increase that would overcome the interference *during a pass by an aircraft transmitting a cochannel signal*. Even with the long string of 'worst case' assumptions which underlie the table, the calculated impact to a good call is equivalent to less than a ½ dB change in path loss. In the terrestrial mobile environment, path loss routinely fluctuates 10-20 dB over short distances as a subscriber moves, so it seems unlikely in the extreme that this *calculated* impact could actually be measured with test equipment in the real world, and the possibility of subjective human observation is vanishingly small... Even in this worst of possible cases, there seems to be no way a reasonable and prudent observer could assert there is a threat of 'harmful interference' here.

Note too that no BER increase will *actually manifest* unless the subscriber is already at maximum transmit power – in which case it is likely he or she is *already* experiencing fades due to the terrestrial propagation environment – and deep fades mean blanking of the audio... This automatic response to BER impact *was not* taken into account in this analysis, so the impacts shown are likely overestimated.

Table 1.2 AirCell BER impact to typical TDMA call, by land use category and case

Case, Aircraft altitude, Omni or Smart AirCell server, Minimum Avg. Signal Strength for $\geq 2\%$ BER	Test Condition AirCell BER Impact %	Weighted AirCell BER Impact to Ground Caller (Rural, Suburban assumed Omni, Urban, Dense Urban assumed sectored.)	Caller Weighting by Land Use	Nationwide AirCell BER Impact, Weighted by land use, caller density
Rural, Low, Omni 2.33% BER @ -104 dBm	0.31 %	$1.3 \times 10^{-4} \%$	22.2%	$2.9 \times 10^{-5} \%$
Suburban, Low, Omni 2.05% @ -98 dBm	0.08 %	$3.4 \times 10^{-5} \%$	30%	$1.0 \times 10^{-5} \%$
Urban, Low, Omni 2.02% @ -90 dBm	0.016 %	$3.4 \times 10^{-6} \%$	35.2%	$1.2 \times 10^{-6} \%$
Dense Urban, Low, Omni 2.29% @ -88 dBm	0.021 %	$4.5 \times 10^{-6} \%$	12.6%	$5.7 \times 10^{-7} \%$
Nationwide, Low, Omni				$4.1 \times 10^{-5} \%$
Rural, High, Omni 2.33% BER @ -104 dBm	0.042 %	$1.8 \times 10^{-5} \%$	22.2%	$4.0 \times 10^{-6} \%$
Suburban, High, Omni 2.05% @ -98 dBm	0.013 %	$5.5 \times 10^{-6} \%$	30%	$1.7 \times 10^{-6} \%$
Urban, High, Omni 2.02% @ -90 dBm	0.0026 %	$5.5 \times 10^{-7} \%$	35.2%	$1.9 \times 10^{-7} \%$
Dense Urban, High, Omni 2.29% @ -88 dBm	0.0035 %	$7.4 \times 10^{-7} \%$	12.6%	$9.3 \times 10^{-8} \%$
Nationwide, High, Omni				$6.0 \times 10^{-6} \%$
Rural, Low, Smart 2.33% BER @ -104 dBm	0.010 %	$4.2 \times 10^{-6} \%$	22.2%	$9.4 \times 10^{-7} \%$
Suburban, Low, Smart 2.05% @ -98 dBm	0.0052 %	$2.2 \times 10^{-6} \%$	30%	$6.6 \times 10^{-7} \%$
Urban, Low, Smart 2.02% @ -90 dBm	0.0011 %	$2.3 \times 10^{-7} \%$	35.2%	$8.1 \times 10^{-8} \%$
Dense Urban, Low, Smart 2.29% @ -88 dBm	0.001 %	$2.1 \times 10^{-7} \%$	12.6%	$2.6 \times 10^{-8} \%$
Nationwide, Low, Smart				$1.7 \times 10^{-6} \%$
Rural, High, Smart 2.33% BER @ -104 dBm	0.00036 %	$1.5 \times 10^{-7} \%$	22.2%	3.4×10^{-8}
Suburban, High, Smart 2.05% @ -98 dBm	0.00014 %	$3.0 \times 10^{-8} \%$	30%	9.0×10^{-9}
Urban, High, Smart 2.02% @ -90 dBm*	0.000024 %	$5.0 \times 10^{-9} \%$	35.2%	1.8×10^{-9}
Dense Urban, High, Smart 2.29% @ -88 dBm*	0.00003 %	$6.4 \times 10^{-9} \%$	12.6%	8.1×10^{-10}
Nationwide, High, Smart				$4.6 \times 10^{-8} \%$

*AirCell presence' weighting factors; 2.12×10^{-4} for sectored sites, and 4.24×10^{-4} for omni sites

Thus, on a nationwide basis;

If AirCell deploys only Omni serving cells, and all AirCell users fly at low altitudes the average terrestrial subscriber can expect a good call at approximately 2% BER to suffer a BER increase of 0.000041% due to AirCell operations

If AirCell deploys only Omni serving cells, and all AirCell users fly at high altitudes the average terrestrial subscriber can expect a 'good' call at approximately 2% BER to suffer a BER increase of 0.000006 % due to AirCell operations.

If AirCell deploys only Smart Antenna serving cells, and all AirCell users fly at low altitudes the average terrestrial subscriber can expect a good call at approximately 2% BER to suffer a BER increase of 0.0000017 % due to AirCell operations.

If AirCell deploys only Smart Antenna serving cells, and all AirCell users fly at high altitudes the average terrestrial subscriber can expect a good call at approximately 2% BER to suffer a BER increase of less than 0.000000046 % due to AirCell operations.

In actual fact, AirCell will likely deploy some mix of Omni and Smart Antenna servers, and AirCell subscribers will fly some mix of altitudes, so the true nationwide expectation will fall somewhere among the cases and values above.

It is not plausible that a terrestrial caller could subjectively detect such an impact against the typical terrestrial fading environment, which creates *much* larger excursions in BER.

What's clear is that the expectation of BER degradation for 'good' terrestrial calls (2% BER or better) due to an AirCell presence is 5 or more orders of magnitude below that existing BER.

This average impact is quite literally 'in the noise' – masked by normal statistical fluctuations in BER during terrestrial calls. No human can be expected to subjectively detect such an impact.

As presented herein, one sees that, given sensitive test equipment and careful measurement technique, coupled with sufficiently extensive simulation, one can numerically estimate a small, *quantifiable* BER impact to a terrestrial call, implicitly assuming herein that in all cases the TDMA caller is at maximum transmit power, and the TDMA system cannot automatically cancel the impact by simply raising the reverse transmit power a step. (Which is the normal response.) But, even then the calculated impact is so small that subscribers cannot subjectively observe it, and the impact cannot, in the opinions of the authors, be considered *in any way* to meet the FCC criteria for 'harmful interference' by a reasonable and prudent observer.

Thus, using conservative assumptions, a worst-case choice of AMPS interferer modulation (SAT only), worst-case flight test data (AirCell callers at low altitude, served by omnidirectional AirCell servers 75+ miles away) and based on both measured TDMA site equipment performance and measured TDMA subscriber signal strength data from a rural environment, it can be concluded that:

Based on the test data and analysis presented herein, full scale AirCell operation, properly deployed and engineered, will be subjectively imperceptible to terrestrial TDMA callers.

Later sections in this report describes in detail the test procedures used, the data collected, calibration/normalization information, and the reasoning process through which these conclusions were reached.

2 Technical Summary

This report is intended to:

- Discuss the test objectives, how the test was structured, and the measures taken to ensure the accuracy of the data, including calibration and normalization of equipment.
- Describe the data taken,
- Describe the postprocessing steps,
- Present the results that arose from the raw data and postprocessing
- Describe the analysis of the data.
- Present our observations and conclusions that follow from the data analysis.

In 1997, flight testing was conducted to definitively answer whether AirCell operations pose a threat of 'harmful interference' to the reverse link of terrestrial AMPS cellular systems. The test was witnessed by the FCC and by opposing parties. After observing the test and examining the test report, the FCC found that contentions of harmful interference by opposing parties were not supported, and has continued to renew the AirCell waiver.

Technology continues to develop. Greater capacity and larger feature sets are now offered by digital protocols. So, increasing portions of the cellular spectrum in many markets are now occupied by digital formats, both CDMA and TDMA. Terrestrial markets still make AMPS channels available for existing customers and roaming purposes, as it is the 'least common denominator' for multimode digital cellular or 1900 MHz PCS phones. Thus, AMPS is likely to be in service for some time to come, sharing the spectrum with digital technologies.

This test was conducted to definitively answer whether AirCell reverse channel operations pose a threat of harmful interference to IS-136 TDMA terrestrial operations. The test was run in several phases, to carefully develop and quality check the data needed for a determination, post process that data into a form which is able to be interpreted, and then present that data.

Test Approach

In order to determine the AirCell operational impact on TDMA terrestrial systems, the test was structured in a series of steps;

First, no data was available regarding the bit error rate performance of site transceivers (known in Nortel nomenclature as "TRU" for Transmit Receive Unit) in the presence of noise and narrowband cochannel interference. It was necessary to directly characterize the Bit Error Rate (BER) performance of these TRUs over a space comprising three dimensions (input parameters);

- 1) Strength of the signal of interest
- 2) Strength of the narrowband (AMPS) interferer
- 3) Background noise level (Rural, Suburban, Urban, Dense Urban cases)

Once the receiver was characterized over this space, it became possible to 'predict' (by table lookup and interpolation) the BER of the radio for given values of these three input parameters.

This allowed construction of a composite experiment using the receiver response space, fed by three bodies of data completing our 'comprehensive data set';

1) Received signal strength data from actual TDMA subscriber calls placed at Lena, gathered over a 24 hour period, providing representative statistics for the strength of the TDMA signal of interest. This data also yielded second-by-second 'transcripts' of the signal strength for all subscriber calls during the period for time-domain analysis.

2) The strength of the AMPS interferer was taken from existing flight test data from the July 1997 test which provided accurate measurements and statistics for AirCell reverse channel signals as observed at a non-AirCell site (Madill, OK) for aircraft flybys at various altitudes, for both omnidirectional and 'smart antenna' AirCell serving site configurations.

3) Typical values for existing noise background in Rural, Suburban, Urban, and Dense Urban regions have been previously reported in the literature, which include both man-made noise and the background noise due to typical cochannel reuse by other cells in the terrestrial system.

The values used were:

-118 dBm total power in 30kHz,	(simulating Rural noise levels*)
-115 dBm in 30kHz,	(simulating Suburban noise levels*)
-107 dBm in 30 kHz,	(simulating Urban noise levels*)
-100 dBm in 30 kHz	(simulating Dense Urban noise levels*)
* (based upon data supplied by U.S. Cellular, Comcast Cellular, TEC Cellular, and other sources)	

Given these three bodies of data, it became possible to conduct a mathematical analysis of the BER that results when all parameters are held constant and the AirCell influence is included or omitted from the processing of 24 hours of subscriber call data. The calculation of BER impact in this manner solves a basic problem, that of how to detect an AirCell *impact* to subscribers.

A direct experiment would have been unwieldy and not as illuminating. For example, subscriber BER data could have been taken from the cellular system for an extended time, several days at least. Then, the collection could have been repeated for a like period, with an AirCell-equipped aircraft continuously traversing the area, 24 hours a day, continuously placing calls. Sounds easy, but keeping an aircraft up 24 hours a day is a problem, *and no two days of subscriber traffic are identical*. Different subscribers drive different routes, using different equipment, talking for different lengths of time... The AirCell impact observed could have been badly skewed or entirely masked by fluctuations due to uncontrolled variables... The chosen method bypasses that uncertainty, by allowing mathematical addition or omission of the AirCell signal from the calculation. The AirCell signal becomes the only changed variable, and the potential for errors and uncertainty in assessing the impact is far less.

To accomplish this experiment, the first measurement step was receiver characterization and cross-checking:

Base station transceiver performance characterization

Three base station radios (TRUs) were selected at random. One was characterized in great detail, then it was removed from the system and each of the remaining pair were in turn placed in the same base station slot and characterized, to corroborate that the chosen TRU was representative of the general population of radios – that its response when presented with signal in noise and interference was not significantly better or worse than average. (The same chassis slot was used for each radio to assure multicoupler performance impacts were identical. Test levels applied to the multicoupler relative to its intercept point were sufficiently low that intermodulation or compression had no effect on measurements.)

The test setup used is shown below in Figure 2.1:

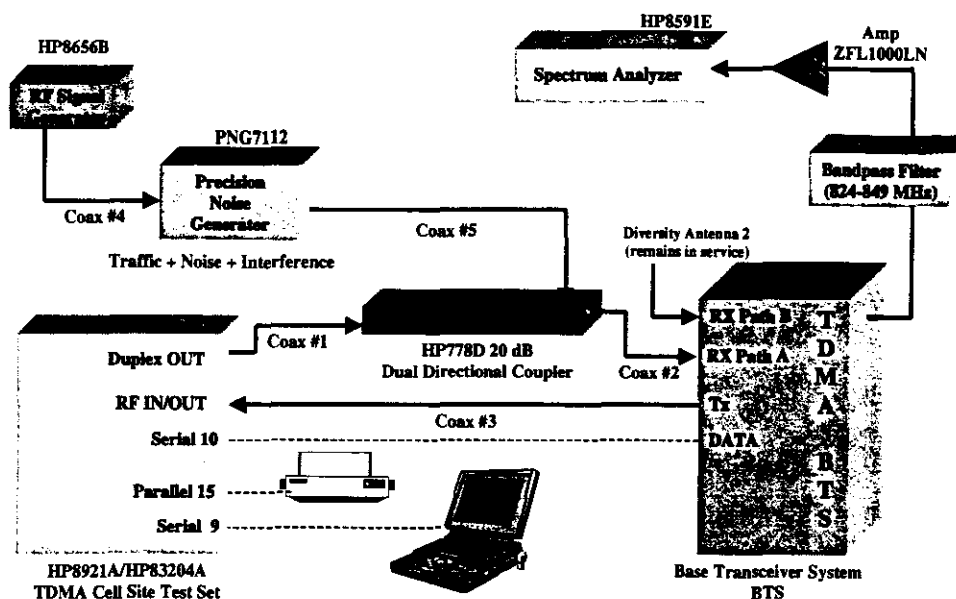


Figure 2.1 Site transceiver characterization setup

The receiver under test remained in the Base Station (BTS) rack, but was removed from service. It was controlled instead by direct RS-232 serial connection to the HP8921A. (The remaining site radios remained in service processing calls) A closed-cabled test hookup was thus made to the radio, so that the signal from the HP-8921A test set could be fed to it through one path of the multicoupler, and the transmitted output from that radio was attached back to the HP8921A. This allowed a 'call' to be set up with total control of the received signal strength, background noise level, and narrowband interference level. *All path gains/losses were carefully calibrated, and amplitudes presented in the data are referenced to the input of the BTS receive multicoupler.*

In the presence of low level background noise and interference, the three radios performed as expected, producing classic 'waterfall' BER curves expected for phase modulated systems:

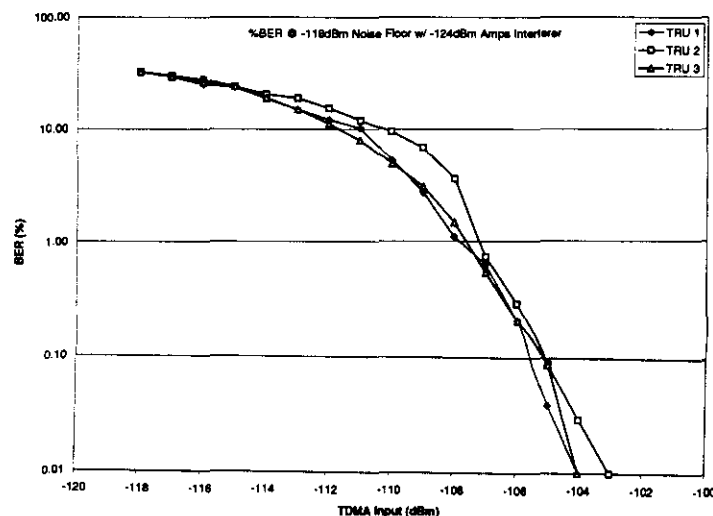


Figure 2.2 Receiver performance comparison example, Rural Noise, -124 dBm AMPS interference

It should be noted that several possible AMPS waveforms were considered for use as the interferer, and a combination of empirical reasoning and experimentation (presented in section 3.3.2) showed that the most disruptive of AMPS signals to IS-136 phase modulation (at a given power level) is SAT-only modulation. SAT-only interferer modulation was chosen for testing, one of many pessimistic or worst-case choices made to avoid undue favoring of the AirCell case.

Table 2.1 Cell site performance with ‘Rural’ background noise level and AMPS interference.

(Note that in this one table, two data points are missing - the test set failed to obtain 'DSP Sync' on the data pattern, and due to human error, the points were not retaken. Interpolation may be used to bridge such missing points.)

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On-Air testing

After characterizing the site transceivers, it was necessary to collect received signal strength data from actual TDMA subscriber calls placed at Lena, gathered over at least a 24 hour period, to provide representative statistics for the strength of the signal of interest. Before this was done, it was necessary to calibrate remaining site signal paths, and to verify proper site coverage and operation:

Site calibration and checkout.

The test site chosen was the US Cellular site in Lena, IL. This is a rural site, with a compliment of Nortel Dual Mode AMPS/TDMA radios. The site was essentially randomly chosen, and local personnel did no unusual performance 'tweaking' prior to the test.

US Cellular records show the following basic site configuration:

- Latitude 42°20'30" North, Longitude 89°49'43" West (NAD 83 datum)
- Ground Elevation 898' AMSL
- 320' overall structure height
- Radiation Centerline at 308' AGL
- Antennas are Kathrein #740198 omni, having 9 dBd gain. Zero downtilt.
- ERP: 145 watts

Only two radios were operating in the IS-136 mode, with the majority operating as AMPS transceivers. Site receive antenna paths were swept to verify proper operation, and the gain of receive multicoupler paths leading to the radios were carefully measured. As the test was conducted over a number of days, both a pre and post test calibration were performed to assure that no significant component drift was experienced, and to show that no multicoupler components failed during testing.

The measured path gains from the input of the Nortel Receive Multicoupler (the reference point) to the receiver tested (at 825 MHz) were:

Path A, +4.4 dB

Path B, +3.6 dB

The 0.8 dB difference was the result of slightly imperfect gain (variable attenuator) settings in the two paths. Both settings are essentially in line with Nortel recommendations:

"It is recommended that the receive path gain be 3 dB unless the system is RF sensitivity limited, that is, in rural applications." (Nortel 411-2131-165, Jan 1995, page 6-10)

The gain at Lena was set only slightly above this level, and it is a rural site.

Estimates were made of tower cable losses prior to the multicoupler, and the antennas were assumed to meet manufacturer gain specifications, so it was possible to calculate the field strength incident at the site using received signal strength measurements.

During the 1997 flight test, site receivers were found to be poor sources of received signal strength (RSSI) measurements for subscriber signals. The early 1980's vintage radios exhibited nonlinearity and poor accuracy at low signal levels. As a result, site radio RSSI data was disregarded in the 1997 test, in favor of data taken using Grayson receivers and Spectrum Analyzers. The Nortel radios at Lena were a far newer design, largely digital in implementation, and reported linearly and accurately down to the point at which the noise floor began to interfere (as theory would indicate) with the measurement. The RSSI response curves for the two on-air TDMA radios (Channels 6 and 1008) using both multicoupler paths are shown below:

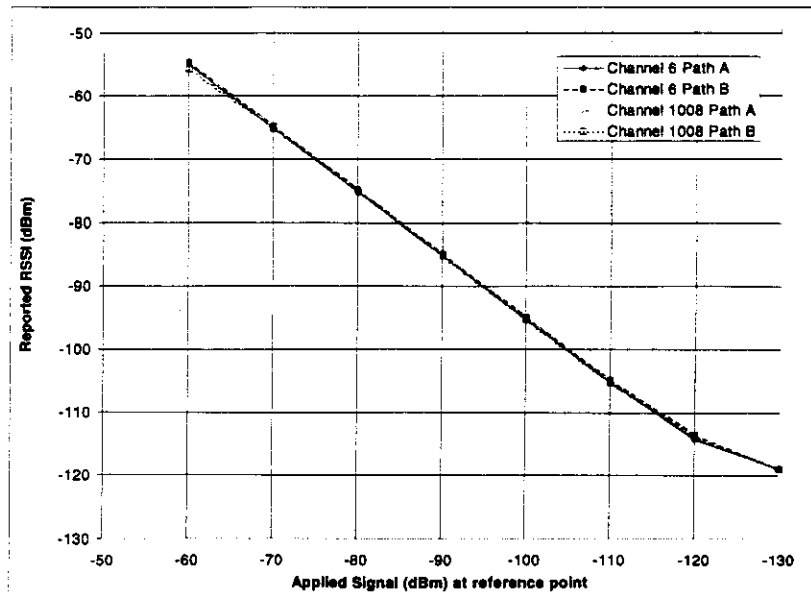


Figure 2.3 Nortel Dual Mode receiver RSSI indication vs. input level at reference point

As a result, the Nortel radios were chosen as the primary data source for collecting reverse channel RSSI data both during drive testing and in collecting subscriber traffic data. Spectrum analyzers were not as useful, as they cannot separate RSSI readings from multiple (timeslotted) subscriber calls on a single channel. The TDMA radios themselves *are* synchronized to incoming TDMA timeslotted burst transmissions, and provide accurate RSSI data.

Spectrum analyzers were used as secondary measurement devices, as they could make measurements of TDMA signals *provided* one and only one timeslot was active at the time (based on transceiver status indications). As usual, the accuracy and linearity of the HP-8590 series analyzers was found to be excellent after self calibration operations were completed.

Referencing

When raw data is to be combined in a mathematical process, such as the one which comprises the interference impact assessment discussed herein, the data *must* share a common reference point, and it must be adjusted to remove sampling artifacts, as appropriate. In other words, the data from various sources must be self consistent, or the result of comparison calculations is not useful.

Referencing the data to the input of the site receive multicoupler was the chosen approach. This reference point was chosen because it is common to all manufacturers' site equipment. The antenna subsystem must feed the site radio equipment at some point, regardless of implementation differences further downstream. This was done for both the 1997 flight test data, which provided AirCell signal levels and for Nortel site receiver data, which provided TDMA subscriber signal strength data. In both cases, multicoupler gains were accurately characterized and subtracted from raw measurements.

Where spectrum analyzers were used, they shared the multicoupler with site transceivers, but to feed them, the signal was tapped as soon as possible after the initial preamplifier (at the splitter intended to feed additional transceiver racks) and additional preamplifiers, filtering, and cabling were utilized. This was necessary because the noise figure of HP-8590 series spectrum analyzers alone is quite poor (20 dB plus), and additional preamplification lowers the effective spectrum

analyzer noise floor. The multicoupler gain for spectrum analyzer paths, including these additional components and the cabling leading to spectrum analyzers were carefully measured and compensated for, so the spectrum analyzers also shared the same amplitude reference point.

Further analysis indicated that small sampling artifacts could be attributed to the measurement equipment. The spectrum analyzers in effect read the peak of approximately 6 TDMA transmission bursts on each sweep, so a small but understood offset was introduced to the measured subscriber TDMA data. The Grayson receivers used in 1997 sampled 400 times per second, averaging each reading in linear watts, before recording min, average, and max values for each data point in dBm. The Nortel receivers sample each TDMA data burst, and takes the mean of *the readings expressed in dBm*. This latter approach is understood in a Rayleigh fading environment to produce an offset relative to linear sampling as used in the Grayson data. This offset was calculated to be 2.5dB by the authors, and this value was confirmed by Nortel documentation.

Diversity 'gain' at the site was also less than theoretically possible, as the antenna spacing vs. installed height was inadequate to achieve full decorrelation. (This is perfectly normal in tall rural sites, and not an unusual implementation issue.)

Section 4.4 presents detailed information and calculations used in data normalization. This normalization corrects data from all measurement sources so it appears to share a common physical measurement point in the system, and share common statistical measurement properties. Examination of the resulting data sets indicated that normalization resulted in accurate and self consistent measurements, suitable for use in the mathematical analysis that followed.

Site performance verification

Proper operation of the site within the cellular system was necessary to show that collected subscriber signal strength data was representative. A malfunctioning site could skew subscriber signal levels significantly.

A drive test of the area surrounding the site was performed, to show that the site did indeed perform as it should, and that subscriber data collected there would be representative of a properly operating site. The initial drive test showed a failure to handoff to the site to the East (Freeport), which was found to be an omission in programming handoff neighbors at the switch (MTSO) controlling Lena and its neighbors during a recent retune. Such human errors occur from time to time in manually entering large data tables during retunes, but they are not 'normal operation'. So, the problem was corrected. Standard handoff parameters were loaded, and the site was confirmed to be operating properly by a second drive test. No special handoff optimization was performed; the parameters used were 'standard' ones used in most of the sites in the area.

Drive testing then showed handoffs taking place in good agreement with the strongest server prediction, run in *WIZARD*[®] (an RF modeling tool) for the area, as shown in Figure 2.4 below. The strongest predicted server is indicated by color fill, with Lena in light blue, Stockton in pink, etc. The actual server for the test call over the driven route was color coded, with Lena in green and any other site indicated in red.

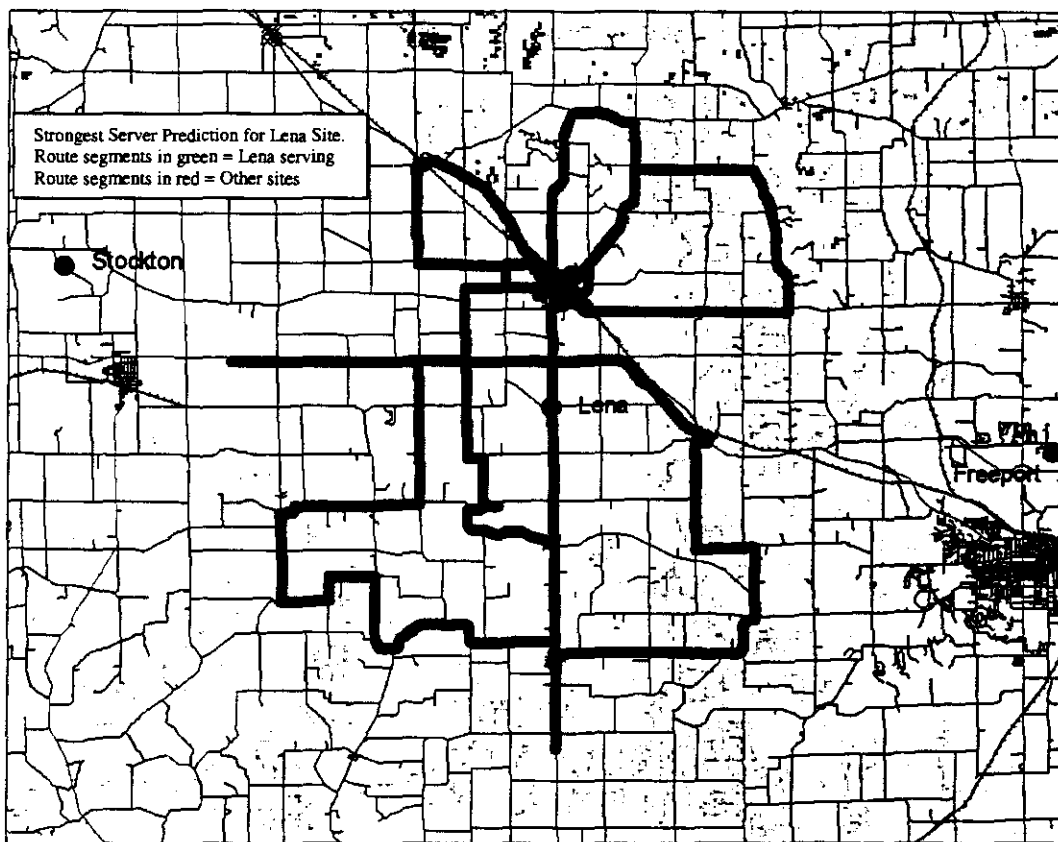


Figure 2.4 Lena predicted strongest server area vs. actual server in drive test

This agreement between predicted and actual coverage area indicates the site was operating properly. There was some handoff 'ping ponging' driving West towards Stockton, due to gentle hills along the road, which created alternately larger/smaller effective antenna heights for Lena and Stockton. A few areas were observed where terrain/foliage blockage caused very poor signal levels, but cell spacing (and terrain) precluded handoff. While this does sometimes happen in rural areas, it's worth noting that coverage (hence call quality) was suboptimal in several places. Further, detailed drive test data is shown in section 4.6.1.

Subscriber Traffic Data Collection

Initially, subscriber traffic signal data collection was attempted with spectrum analyzers only, using a setup and software essentially identical to that used for the 1997 flight test. As there were only two TDMA channels at the site, one had the control channel timeslot and was always keyed (channel 1008), while the other carried three voice channel timeslots (channel 6). It was decided to disable two of the three voice timeslots on channel 6, and monitor the forward channel (with a spectrum analyzer) to determine when a call was being carried on the remaining slot, allowing reverse channel data gathering. Unfortunately, after 52 hours of data collection, only about 2 ½ hours of calls were placed on this radio. This was not enough to be statistically significant. Investigation revealed that the system 'trunked' selectively to first use the two voice timeslots in channel 1008, which is always keyed. It keyed channel 6 only when 1008 was 'full'. This also meant that collected data on channel 6 would be skewed, reflecting mainly peak traffic periods... Another way was needed.

Site documentation provided diagnostic methods to be used with Nortel TRUs. It was found that the serial data connector on the front of every radio could be used to query radio RSSI, and that the response included both flags showing which timeslots were active, and the signal strength

reading. A computer program was written by WSE to query both TDMA radios once per second, and record the result of each query along with a GPS time stamp data to a file. This did not affect call processing by the radios.

A second data collection attempt was made, using both radios and the spectrum analyzers. This time, the radios provided data indicating when a single timeslot was active, so spectrum analyzers could collect data on both channels 1008 and 6.

The spectrum analyzers provided a backup confidence check for receiver data, but the receiver data was the prime data source, as it could provide information on up to the maximum 5 simultaneous TDMA calls processed by the site – Monitoring the site receivers allowed *all* subscriber data to be collected during the period, rather than a partial sampling.

After 24 elapsed hours, 724 subscriber calls were monitored, totaling 19 ½ *hours* of subscriber signal strength data. This was considered adequate for statistical significance, and postprocessing.

The subscriber signal strength data is presented as a histogram in Figure 2.5. This histogram represents signal levels for random subscribers placing calls in the coverage area using various phone makes/models, as influenced by normal site Dynamic Power Control (DPC) operation.

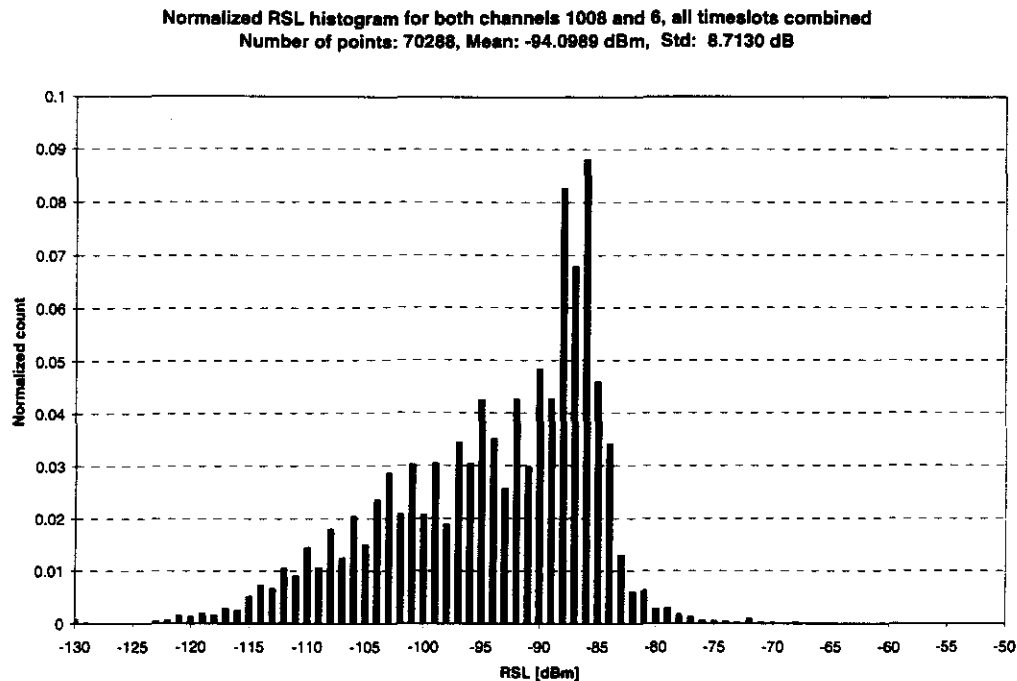


Figure 2.5 Subscriber call data - received signal level histogram.

Section 4.6.2 presents more detailed information, and channel 6 was found to exhibit some bimodality in measured data. In addition to the peak at -86 dBm, another manifested at -102 dBm. The reason for the second peak is not known, but it may be related to a specific location or locations that carried significant traffic during peak times, such as U.S. Route 20 or IL Rt. 73 which ran adjacent to the site. It is significant that, based on our BER measurements, below -109.2 dBm (in a rural environment) call quality will be degraded. Thus, *over 6 ½% of all the call-seconds seen at this site were at levels low enough that voice quality will be degraded prior to considering any AirCell impact.*

Data postprocessing and results

As noted previously, one of the prime metrics used by IS-136 carriers to assess system performance is bit error rate. After the site receiver BER response was characterized and the subscriber data taken, it became possible to postprocess the data to predict the second-by-second BER subscribers should have experienced during those calls with no AirCell cochannel reuse present, calculate it again *with* an AirCell presence, and determine the second-by-second AirCell impact to BER, and examine the effect on subscriber call quality. The postprocessing steps were as follows:

1. Select a land use condition; Rural, Suburban, Urban, or Dense Urban. Select the appropriate BER lookup table (such as Table 2.1).
2. Select the 1997 flight test observer site received signal strength histogram reflecting the flight profile (High or Low altitude) and AirCell serving site configuration (omni or smart antenna). Since the 1997 flight test utilized the same amplitude referencing point in the cell site receiving system, direct comparison of the data can be performed.
3. Perform a dot product of the flight test histogram with a row of the BER lookup table, in which signal levels are aligned. This yields the BER expectation for the TDMA signal level corresponding to that row. Also, note the 'no interferer' BER value from that row.
4. Repeat step 3 for all rows in the table. The result is a list of expected BERs for each TDMA signal level, with and without interference present.
5. Obtain TDMA subscriber reverse link signal level in second-by-second time domain form, extracting each call individually from the 24 hour data.
6. For each subscriber call, calculate the mean received signal strength level.
7. For each second of the call, note the signal strength, and look up the BER expectation for the no interferer present and selected flight profile cases. The difference is the BER impact for that second.
8. Accumulate BER and BER impact values for the duration of the call. Aggregate the results for calls having the same mean received signal strength, as determined in step 6.

The results can be presented as an impact vs. mean call signal strength graph. An example is shown in Figure 2.6 below for the *worst case – that of a rural observer cell, with the AirCell caller flying by at low altitude, while being served by an AirCell site 75+ miles away.*

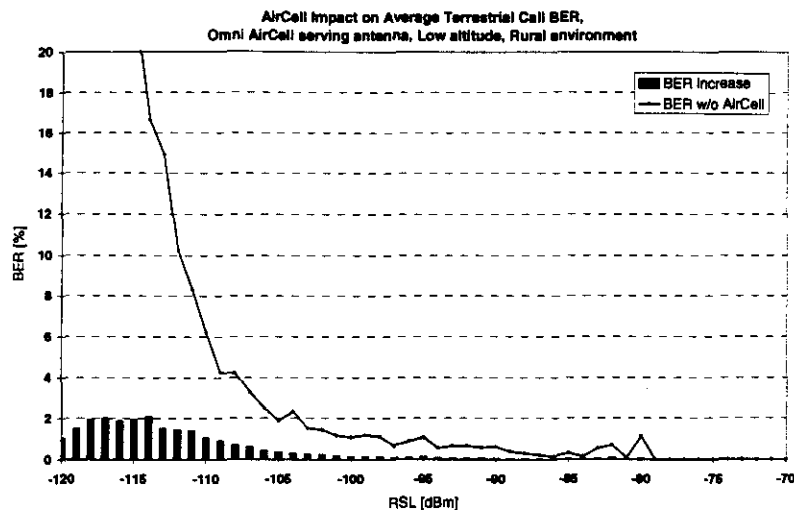


Figure 2.6 BER and AirCell impact, Rural environment, Low altitude, Omni AirCell server (worst case)

Figure 5.2 through Figure 5.17 present the graphs for other cases.

Note: In many of these figures, it was necessary to magnify the scale of the impact by a factor of 10 to 1000 in order to make it at all visible on the plots. The legend in the upper right corner of each plot indicates when this was done. Note also that the largest impact magnitude takes place at low TDMA signal levels where BERs were far above the 2% 'good call quality' BER

target - where call quality is *already* significantly degraded and the additional impact is proportionately smaller... (Tabular data representing this graphical data is presented in Appendix B - Tabular Data, BER Impact of AirCell Signal.)

Other presentation formats for BER results and BER impact are included in section 5.2. In examining the data, including the intermediate results from step '4' above, it becomes clear that as altitude increases, the AirCell influence decreases very significantly, and that as one moves from rural to suburban, urban, and dense urban areas, the BER impact progressively decreases. The use of smart antenna systems by AirCell also produces an across the board reduction in impact, as aircraft transmit level is decreased significantly.

Another pattern emerges: *The AirCell impact, viewed in the 1 dB resolution of the tabular data, does not push a 'good' call having a mean BER of $\leq 2\%$ 'over the edge'.*

Interpolating the BER tables into 0.1 dB steps to better utilize the subscriber data (which has tenth-dB resolution) it's possible to observe that *a rural caller carrying a 'good' call at 2% BER will experience only a 0.3% BER impact for the duration of a cochannel AirCell flyby* (at low altitude, with an omni AirCell server 75+ miles away). This is equivalent to less than a ½ dB change in path loss to the subscriber. *It is unlikely in the extreme that even the most discerning cellular subscriber could subjectively detect this impact.* Again, higher altitude and more densely populated areas make this impact substantially less. The impact is in fact so low that while it is possible to calculate, it vanishes for all practical purposes in many cases.

NOTE: *Throughout this report, we speak of 'interference' or 'AirCell induced interference' repeatedly. These are sensitive terms, the precise meaning of which lies at the heart of this discussion. AirCell signals, like terrestrial cochannel reuse, adjacent channel reuse, and other man-made noise mathematically 'interferes' with terrestrial cellular signals, just as the thermal noise floor limits system design and operation. If this 'interference' from AirCell operations remains sufficiently low that its contribution to TDMA bit error rate does not cause that error rate to rise sufficiently to degrade call quality, then subscribers cannot observe it – subjectively, it doesn't interfere. That does not mean that the 'interference' is not measurable and quantifiable using sensitive test equipment and sophisticated analytical techniques.*

The distinction between measurable or quantifiable interference and 'harmful interference' – that the latter is apparent to subscribers, to the point that it 'obstructs or repeatedly interrupts' terrestrial cellular operations, is a critical one. Interference cannot become harmful unless it first manifests in a way observable by subscribers.

Another way to present the calculated data is to interpolate again between data points and look at the operating point change that an AirCell impact could cause. That is...calculate the change in received subscriber signal level that would overcome the BER impact of an AirCell subscriber flyby. The results, not including the situational probability that such a flyby will occur, (or that the transmissions will be cochannel) are shown below in Table 2.2.

It's interesting to note that IS-136 systems control subscriber transmit power not only by observing RSSI, but BER as well. *IF* a BER impact from any noise or interference source pushes a call beyond the target BER (usually 2%) the system responds by asking for an increase in subscriber transmit power. Thus, even the impact shown in Table 2.2 below *will not manifest* unless the subscriber is already at maximum transmit power – in which case it is likely he or she is *already* experiencing fades due to the terrestrial propagation environment – and deep fades mean blanking of the audio... This automatic response to BER impact *was not* taken into account in this analysis, so the impacts shown are likely overestimated.

Table 2.2 shows the incremental power increase that would overcome the AirCell interference contribution *during an overhead pass by an aircraft transmitting a cochannel signal*. Even with the long string of 'worst case' assumptions which underlie this situation, the calculated impact to a good call is equivalent to less than a ½ dB change in path loss. In the terrestrial mobile environment, path loss routinely fluctuates 10-20 dB over short distances as a subscriber moves, so it seems unlikely in the extreme that this *calculated* impact could actually be measured with test equipment in the real world, and the possibility of subjective human observation is vanishingly small... Even in this worst of possible cases, there seems to be no way a reasonable and prudent observer could assert there is a threat of 'harmful interference' here.

Table 2.2 AirCell Impact to 2%BER reverse channel operating point for IS-136 'Good quality' call (signal to signal comparison, no situational probability)

Case, Aircraft altitude, Omni or Smart AirCell server	Signal Strength at which ≥2% BER is first reached With AirCell	Signal Strength at which ≥2% BER is first reached W/O AirCell	AirCell Impact to 2% BER Operating Point (Reverse channel transmit power)
Rural, Low, Omni	-103.40 dBm	-103.73 dBm	0.33 dB
Rural, High, Omni	-103.40 dBm	-103.45 dBm	0.047 dB
Rural, Low, Smart	-103.40 dBm	-103.41 dBm	0.012 dB
Rural, High, Smart	-103.40 dBm	-103.40 dBm	4.2×10^{-4} dB
Suburban, Low, Omni	-97.07 dBm	-97.17 dBm	0.10 dB
Suburban, High, Omni	-97.07 dBm	-97.09 dBm	0.017 dB
Suburban, Low, Smart	-97.07 dBm	-97.08 dBm	7.0×10^{-3} dB
Suburban, High, Smart	-97.07 dBm	-97.07 dBm	1.8×10^{-4} dB
Urban, Low, Omni	-89.03 dBm	-89.05 dBm	0.024 dB
Urban, High, Omni	-89.03 dBm	-89.03 dBm	3.9×10^{-3} dB
Urban, Low, Smart	-89.03 dBm	-89.03 dBm	1.6×10^{-3} dB
Urban, High, Smart	-89.03 dBm	-89.03 dBm	3.6×10^{-5} dB
Dense Urban, Low, Omni	-87.62 dBm	-87.67 dBm	0.042 dB
Dense Urban, High, Omni	-87.62 dBm	-87.63 dBm	7.3×10^{-3} dB
Dense Urban, Low, Smart	-87.62 dBm	-87.62 dBm	2.6×10^{-3} dB
Dense Urban, High, Smart	-87.62 dBm	-87.62 dBm	6.6×10^{-5} dB

Probability of Interference and Impact Assessment

It is appropriate to note that the above data *assumes that all the conditions necessary for interference to manifest are present*. This is NOT always the case.

Taking the point of view of an average terrestrial caller, section 6.2 and section 6.3 look at the probability that these conditions are met:

- 1) The AirCell customer is airborne
- 2) The AirCell customer is placing a call,
- 3) The AirCell voice channel is cochannel with a channel at the ground cell being observed,
- 4) The cochannel ground cellular channel is carrying a simultaneous call,
- 5) The aircraft passes near or overhead the ground cell of interest.

The resulting impact to a typical terrestrial call is far less when these probabilities are considered, as shown below in Table 2.3. This table shows the average BER impact that a terrestrial caller can expect when AirCell traffic density and channel planning are considered. (See section 6.2 for detailed calculations and assumptions.)

Table 2.3 BER impact to typical terrestrial TDMA caller

Case, Aircraft altitude, Omni or Smart AirCell server, Maximum Signal Strength for $\geq 2\%$ BER	Test Condition AirCell BER Impact %	Weighted AirCell BER Impact to Ground Caller (Suburban, Rural assumed Omni, Urban, Dense Urban assumed sectored.)
Rural, Low, Omni 2.33% BER @ -104 dBm	0.31 %	$1.3 \times 10^{-4} \%$
Rural, High, Omni 2.33% BER @ -104 dBm	0.042 %	$1.8 \times 10^{-5} \%$
Rural, Low, Smart 2.33% BER @ -104 dBm	0.010 %	$4.2 \times 10^{-6} \%$
Rural, High, Smart 2.33% BER @ -104 dBm	0.00036 %	$1.5 \times 10^{-7} \%$
Suburban, Low, Omni 2.05% @ -98 dBm	0.08 %	$3.4 \times 10^{-5} \%$
Suburban, High, Omni 2.05% @ -98 dBm	0.013 %	$5.5 \times 10^{-6} \%$
Suburban, Low, Smart 2.05% @ -98 dBm	0.0052 %	$2.2 \times 10^{-6} \%$
Suburban, High, Smart 2.05% @ -98 dBm	0.00014 %	$3.0 \times 10^{-8} \%$
Urban, Low, Omni 2.02% @ -90 dBm	0.016 %	$3.4 \times 10^{-6} \%$
Urban, High, Omni 2.02% @ -90 dBm	0.0026 %	$5.5 \times 10^{-7} \%$
Urban, Low, Smart 2.02% @ -90 dBm	0.0011 %	$2.3 \times 10^{-7} \%$
Urban, High, Smart 2.02% @ -90 dBm	0.000024 %	$5.0 \times 10^{-9} \%$
Dense Urban, Low, Omni 2.29% @ -88 dBm	0.021 %	$4.5 \times 10^{-6} \%$
Dense Urban, High, Omni 2.29% @ -88 dBm	0.0035 %	$7.4 \times 10^{-7} \%$
Dense Urban, Low, Smart 2.29% @ -88 dBm	0.001 %	$2.1 \times 10^{-7} \%$
Dense Urban, High, Smart 2.29% @ -88 dBm	0.00003 %	$6.4 \times 10^{-9} \%$

'AirCell presence' weighting factors; 2.12×10^{-4} for sectored sites, and 4.24×10^{-4} for omni sites

Thus, a typical TDMA caller can expect his nominal 2% BER to increase by an average of between 0.0000000064% and 0.00013% due to AirCell subscriber activity, depending upon his location, AirCell subscriber altitude, and AirCell serving site configuration. *Assuming that the subscriber is at maximum transmit power, and dynamic power control does not automatically cancel the impact.*

This calculated impact is far too small to be *directly* observable by any means against a 2% 'background' BER, and the possibility of subjective observation by human subscribers is effectively nonexistent.

Nationwide Impact Estimate

If, as a final step, these impacts are averaged to account for the number of subscribers present in Rural, Suburban, Urban, and Dense Urban environments, a nationwide expectation of impact to a typical terrestrial caller can be estimated (see section 6.2.3 and Table 1.2):

If AirCell deploys only Omni serving cells, and all AirCell users fly at low altitudes the average terrestrial subscriber can expect a good call at approximately 2% BER to suffer a BER increase of 0.000041% due to AirCell operations

If AirCell deploys only Omni serving cells, and all AirCell users fly at high altitudes the average terrestrial subscriber can expect a 'good' call at approximately 2% BER to suffer a BER increase of 0.000006% due to AirCell operations.

If AirCell deploys only Smart Antenna serving cells, and all AirCell users fly at low altitudes the average terrestrial subscriber can expect a good call at approximately 2% BER to suffer a BER increase of 0.0000017% due to AirCell operations.

If AirCell deploys only Smart Antenna serving cells, and all AirCell users fly at high altitudes the average terrestrial subscriber can expect a good call at approximately 2% BER to suffer a BER increase of less than 0.00000046% due to AirCell operations.

Since some mix of flight altitudes and serving cell type will likely exist, the actual expected impact will lie somewhere between these cases. It is obvious that against the (constantly fluctuating) 2% 'background BER' that exists in good calls, that even the largest of these calculated impacts is unobservable by any direct means, and no human subscriber could be expected to subjectively detect an impact many orders of magnitude below the ambient BER.

Thus, it is clear that a properly engineered AirCell system will pass unobserved by terrestrial TDMA subscribers. The conclusion that arises naturally from this analysis is that 'harmful interference' per FCC definition, is not a reasonable possibility.

A final comment is in order. In any statistical argument, 'expectation' has a specific mathematical meaning. It does not preclude the observation or deliberate creation of improbable 'corner case' exceptions in which observable BER impacts manifest. The country is large, varied, and such a case *might* be found or created someday, somewhere. However, interference management is routine RF engineering in the cellular world... Terrestrial operators observe interference situations and correct them routinely. AirCell has a number of applicable engineering options which can be used to mitigate or eliminate such a case. So, if one is ever detected, it should be transient in nature, existing only until the appropriate corrective steps can be taken.